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The Effect of Equatorial Ionospheric Irregularities
on the Performance of a South-Looking OTH-B Radar

Gary S. Sales

University of Lowell
Center for Atmospheric Research
450 Aiken Street
Lowell, Massachusetts 01854

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NorthWest Research Associates, Inc.
300 120th Avenue Northeast
Bellevue, WA 98009

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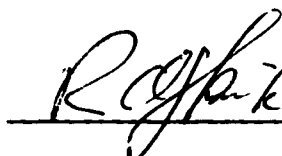


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THE EFFECT OF EQUATORIAL IONOSPHERIC IRREGULARITIES ON THE PERFORMANCE OF A SOUTH-LOOKING OTH-B RADAR

Gary S. Sales

1.0 INTRODUCTION

Ionospheric irregularities are a cause of wideband clutter on OTH backscatter radars that operate at HF (6-30 MHz) frequencies. The conditions for producing this clutter depend on many factors, all of which must be considered when trying to estimate the degree to which the performance of a particular radar system might be degraded. These effects have been discussed in detail in a variety of works most of which apply to the auroral regions where intense irregularities are known to exist and the conditions for backscatter are easily fulfilled.

This clutter is best described in terms of scatter from an irregular ionosphere with a scale of structure sizes that typically include those down to one-half of the wavelength at the radar operating frequency. A general effective scattering mechanism is described by Sales (1987) in terms of specular scatter which includes, as a special case, the classical orthogonal scatter. Orthogonal scatter requires the rays to be perpendicular to the long axes of the ionospheric irregularities. Typically the long axis of the irregularities is aligned with the earth's magnetic field. In the auroral zone the earth's magnetic field is near vertical (70° to 80° from the horizontal). The specular scatter mechanism is a more general concept than orthogonal scatter and can produce clutter over a wide range interval including the region of ground clutter where targets are normally detected.

At these ranges the clutter produced by ionospheric irregularities appears as multiplicative noise making the detection of targets more difficult.

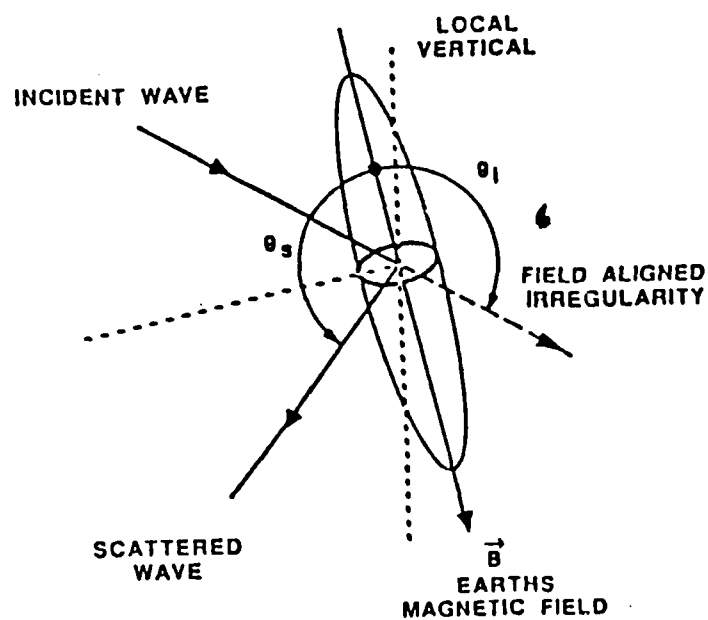


FIGURE 1 Geometry of specular scatter from a field-aligned ellipsoidal irregularity.

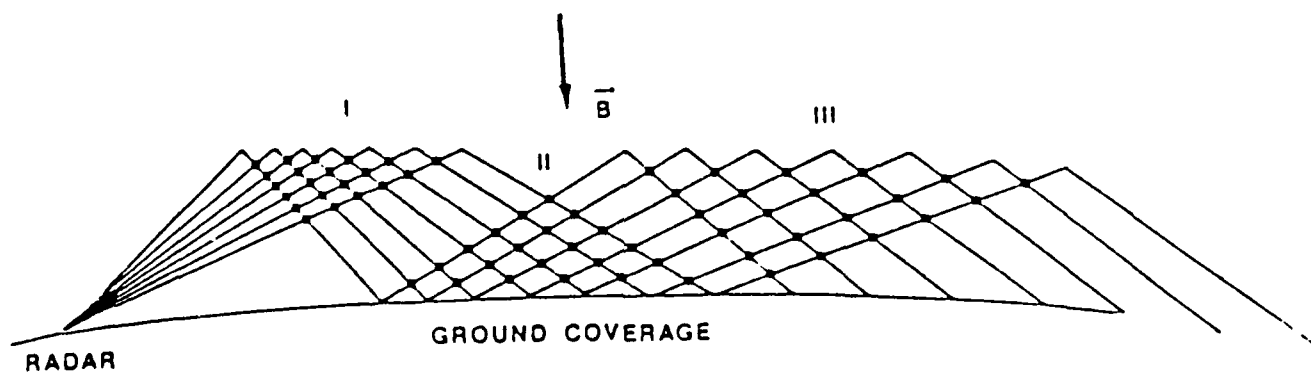


FIGURE 2 Schematic diagram showing potential specular scatter regions (dots).

Specular scatter is a relatively simple mechanism that is best described using Figure 1. This figure depicts a field-aligned irregularity with an overall ellipsoidal shape. A wave incident at an angle θ_i with respect to the long axis of the irregularity (the direction of the earth's magnetic field at that point), scatters at an equal angle (specular) in the plane of propagation. It is clear that orthogonal scatter is a special case of specular scatter, that is where $\theta_i = 90$ degrees.

In order for specular scatter to affect the radar, the scattered wave has to be able to return to the receiver. A raytracing schematic (Figure 2) shows areas marked by dots, where "outgoing" rays cross over. If field aligned irregularities exist in these areas, and if for a downgoing ray the scatter angle θ_s (see Figure 1) is closely aligned with the corresponding upgoing ray (or vice versa), specularly scattered energy will return to the receiver.

The conditions for specular scatter, including orthogonal scatter, are relatively easily met when a radar looks towards the north from a midlatitude site. Although the specular condition can be met at a particular location, clutter will appear at the radar only when intense irregularities are found at the same location.

Conventional wisdom indicates that as the radar points more towards the south the potential for ionospheric clutter ought to decrease for two reasons. Firstly, the condition for specularity becomes more difficult to meet because the magnetic field along which the irregularities are aligned, has become more horizontal, typically 30° dip angles at low latitudes and $DIP = 0^\circ$ at the magnetic equator. In the magnetic meridian plane, pointing directly south, with the typical radar elevation angles of 5° to 20° required for long range ground coverage, it is in general not possible to meet the specular or orthogonal condition.

On the other hand, it must be remembered that the proposed south looking radar will scan over a range of azimuths, such that the ray paths cross the magnetic equator region with a range of angles relative to the earth's magnetic field. This scanning requirement along with the introduction of the specular scatter model and a model of the equatorial ionosphere which realistically describes the complex gradients that effect the rays' paths, suggest it is prudent to take a new look at the question of equatorial ionospheric irregularities as a source of radar clutter.

There have been reported observations of equatorial clutter with the Experimental Radar System located near Bangor, ME (1980-1981) operating in a special mode using a very low waveform repetition frequency that permitted unambiguous long range observations. These results need to be examined to determine if they can be explained with this new scattering model.

First we will look at the ray tracing procedures which includes the specular scatter model and then we will introduce the equatorial ionospheric model and determine the regions that may be potential sources for ionospheric clutter. Finally the existence of irregularities will be analyzed and compared to determine if there is an overlap between the regions where the specularity condition is met and the location of the irregularities.

2.0 APPROACH

2.1 Ray Tracing

A specially developed version of the Jones and Stephenson (1975) ray tracing program is used here to investigate the geographic distribution of specular scatter. This program, developed by Sales at RADC in 1985, can compute the range and altitude distribution of the occurrence of specular scatter. The angular dependence of specular scatter is in the form of a conical region with the forward propagating ray direction as a directrix of the cone, and the axis of the cone is the axis of the elongated irregularity. In addition this scattering cone has a finite width depending on the axial ratio of the irregularities involved in the scattering. As the axial ratio (R) increases from an almost isotropic ($R = 2$) to highly elongated irregularities the width of the scattering cone decreases from about $\pm 20^\circ$ to less than 5° . We have assumed values of $R \leq 5$ so that $\pm 10^\circ$ is the limit we have set for the deviation from exact specularity.

For all the calculations reported here, the original ray tracing program, which is a full 3-D program was reduced to 2-D, thereby simplifying the interpretation of the results. The additional complication of off-great circle propagation does not contribute to our basic understanding of the clutter problem.

2.2 Equatorial Ionospheric Model

For this basic study of the sources of multiplicative noise, it was decided to use the IONCAP (1983) code to specify the structure of the ionosphere and to determine the associated clutter. The main features of the

equatorial ionosphere are represented in this model and using the ray tracing program it will be possible to map the location of the clutter regions over a wide extent in range and azimuth. For ionospheric clutter to exist at these locations requires the existence of small scale irregularities in the region where the specular condition is satisfied.

For this study we have produced ten autumnal equinox ionospheric models, for two times of day (1200 LT and 0000 LT) and for five (5) azimuths directed out of the selected radar site (45.1°N , 263.0°E). The five selected azimuths are 120, 150, 180, 210 and 240 degrees from true north. In each case the models were extended out to ranges of 7500 km from the radar to reach the regions of the magnetic equator.

One problem encountered when using IONCAP over such great distances is that the propagation path crosses several time zones. IONCAP can only compute a model using integer hourly values. These one hour jumps associated with the time zones cannot be simply corrected for by joining the different models across the time change. Simple joining produces large discontinuities which affect the resultant ray tracing. The approach taken here was to compute one ionospheric model for each time zone traversed by the ray path and smoothly join these using a Lagrange interpolation scheme. This produced the two dimensional range-height plots of constant plasma frequency contours shown in Figures 3 and 4. This method generates a rather smooth version of the ionospheric features associated with the equatorial region. This is true for all azimuths except for the 180 degree azimuth where the path does not cross any time zones. For the 180 degree azimuth, no interpolation was necessary and the geographical ionospheric structure is presented directly.

IONCAP 2-D ELECTRON DENSITY PROFILES LOCAL NOON (RADAR SITE)

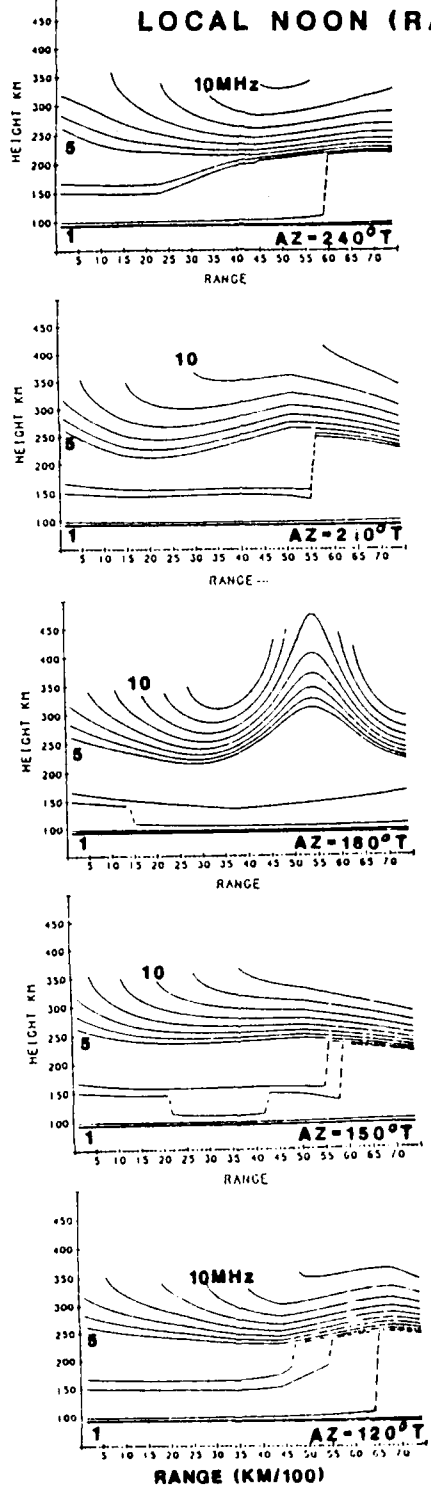


FIGURE 3 Range-height contours of constant plasma frequency; five azimuths; local noon at the radar site.

IONCAP 2-D ELECTRON DENSITY PROFILES LOCAL MIDNIGHT (RADAR SITE)

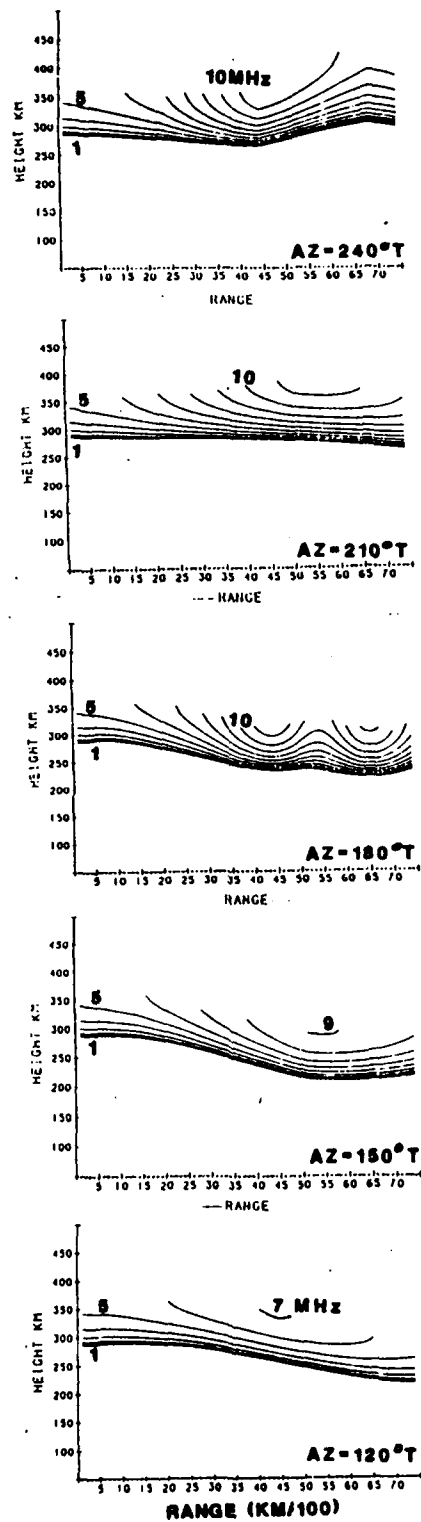


FIGURE 4 Range-height contours of constant plasma frequency; five azimuths; local midnight at the radar site.

Although most of these 2-D profiles are somewhat nonphysical because of this smoothing, the analysis of the occurrence of clutter remains valid and can be used to assess the magnitude of the problem for a radar looking south into the equatorial region.

Finally, we have developed a better method to generate these 2-D profiles that would preserve all the spatial structure. This method would compute the local electron density profiles at points along the ray path separated by one degree spatially using the two hourly time values that bound the actual local time. Then we would use a linear interpolation to estimate the correct electron density value at each height for the exact local time at each point along the path. This method would keep all the spatial structure (one degree steps) and use a linear estimation method for the local time. This method will be utilized in all future studies.

3.0 RESULTS AND CONCLUSIONS

The relationship between the radar "look" directions and the magnetic equator is shown in Figure 5. Depending on azimuth, the ray paths cross the equatorial region at ranges between 6000 and 8000 km. It is within ± 5 degrees of the magnetic equator that the occurrence of intense irregularities is most probable, particularly at night.

The specular scatter calculations analyzed here are for the nighttime and were carried out using a four hop ray path out to distance of about 7000 km. Figure 6 shows the ray tracing results where the plotting of the actual rays has been suppressed. We indicate the intersections of the rays (see Sales (1987)) by small + symbols; where those intersections satisfy the specular condition, they are indicated by the Δ symbol.

For all of the data at night (and in the daytime also) the specular scatter points are confined to the one hop region, that is for ranges less than 2000 km. The conclusion can be drawn that when looking along southerly bearings from CONUS, the condition for satisfying specularity cannot be met because of the more or less horizontal inclination (dip) of the earth's magnetic field. This conclusion is also valid away from the exact southlooking bearing to the 120 degrees true azimuth.

An important question to be answered is whether these calculations indicate that equatorial clutter can become more likely as the radar bearing turns towards the north. These calculations need to be carried out and checked against the Navy's CHURCH EYE data.

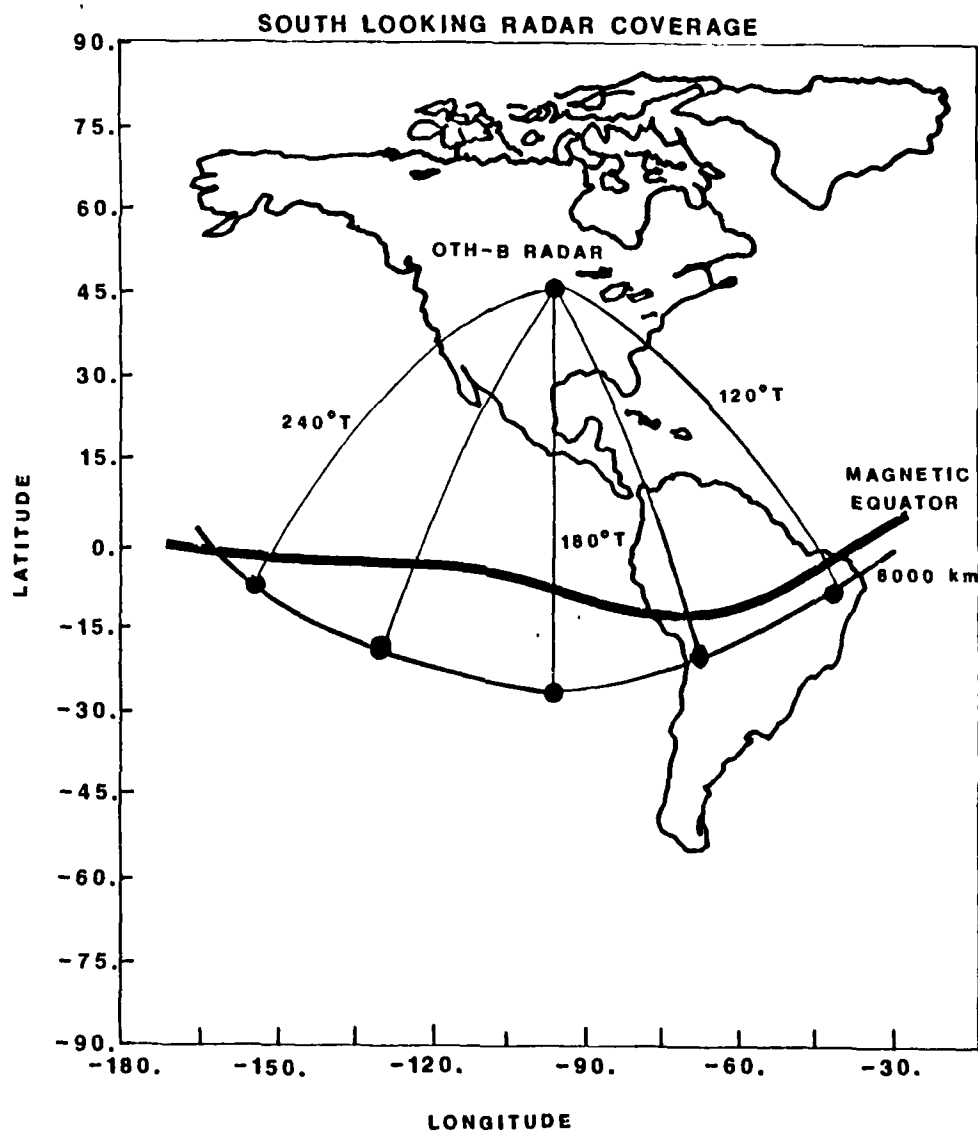


FIGURE 5 Radar azimuthal coverage.

**2-D RAY TRACING
AZIMUTH = 120° T
LOCAL NOON**

**+ RAY INTERSECTION
Δ SPECULAR SCATTER POINT**

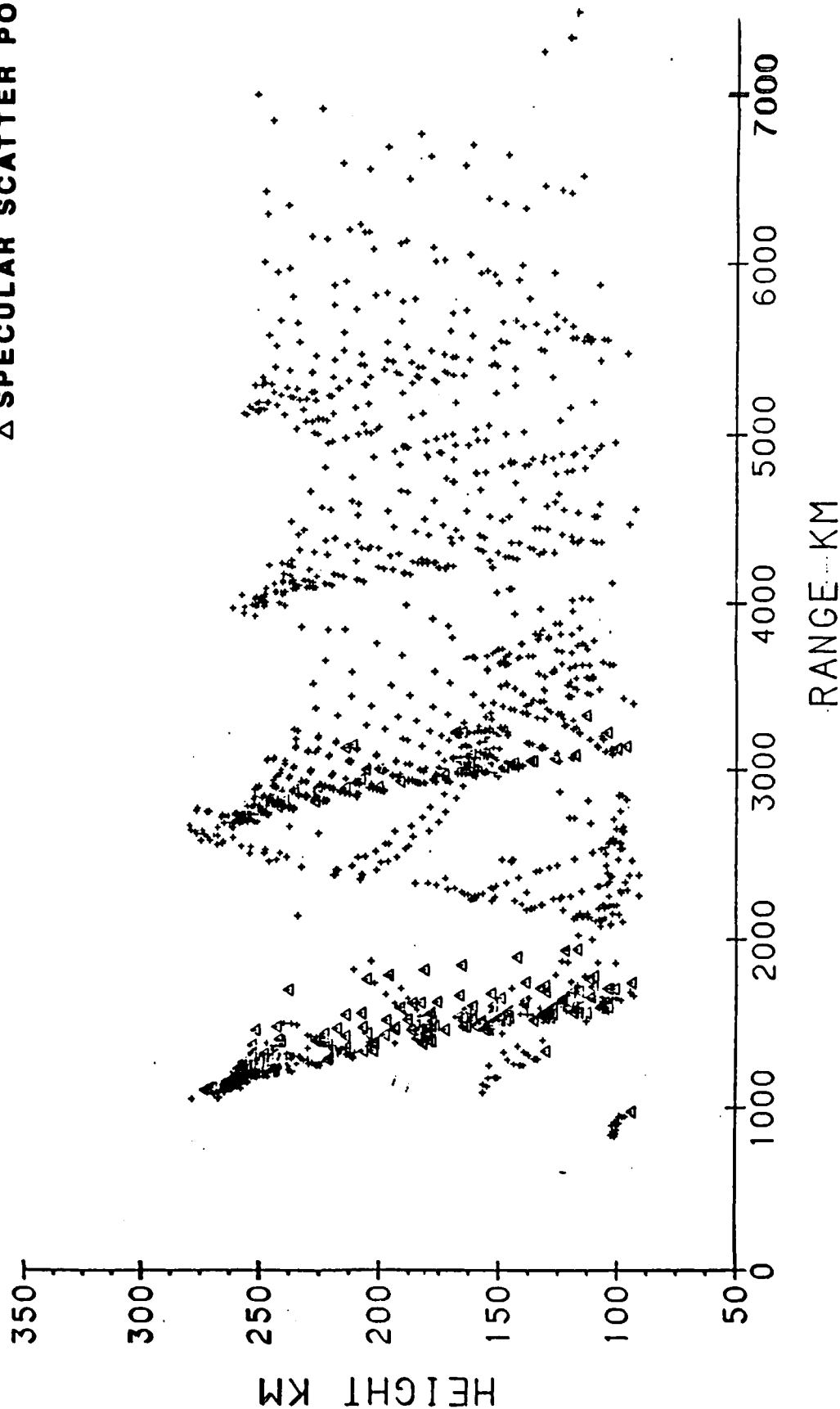


FIGURE 6 2-D ray tracing results showing points that satisfy specular condition.

Finally, we show on Figure 7 the geographical distribution of the specular clutter as seen for the bearings from 120° to 240° T. It must be remembered that these calculations indicate where the necessary condition for clutter is satisfied, but do not address the question of the existence of irregularities at the same location. Without irregularities present there will be no radar clutter. For both day and night in these calculations, the radar frequency was selected so that the skip distance was about 1900 km from the radar site. The potential ionospheric clutter regions lie at ranges from 1000 to almost 3000 km from the radar, the far range varying with azimuth as in Figure 7.

We can conclude that for azimuths between 120° and 240° the likelihood of clutter as a problem to the south-looking OTH-B radar is small. With the typical 2000 km range start for the coverage region, the specular (and orthognal) cluuter locations do not conicide with the equatorial irregularity region.

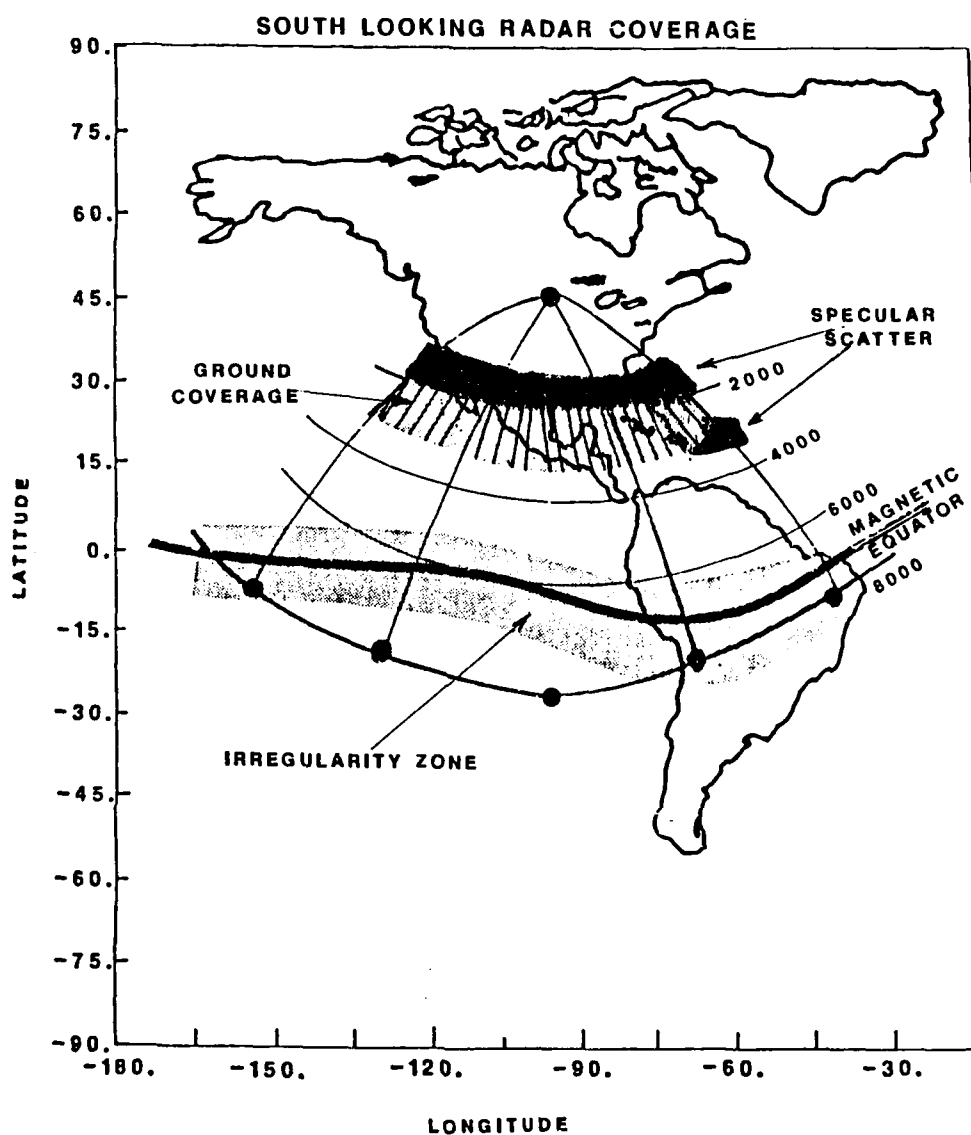


FIGURE 7 Location of ground clutter and specular clutter relative to the CONUS south-looking OTH-B radar ground coverage.

4.0 FUTURE PLANS

The new method for computing spatially realistic ionospheric models from the IONCAP code as described in Section 2.2 of this report will be implemented at least for the 120 degree azimuth. This will serve as a check on our current calculations and whether any or all might have to be repeated.

In addition we will perform a new calculation using this new method for the ionospheric modeling, for the location of the East Coast radar system. Using an azimuth of 76.5° true, we will try to reproduce the CHURCH EYE results discussed earlier. It is also necessary that we take a detailed look at any additional radar data from the Navy experiments. This complete work will make an important contribution to our understanding of ionospheric clutter as seen by OTH-B radar systems.

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